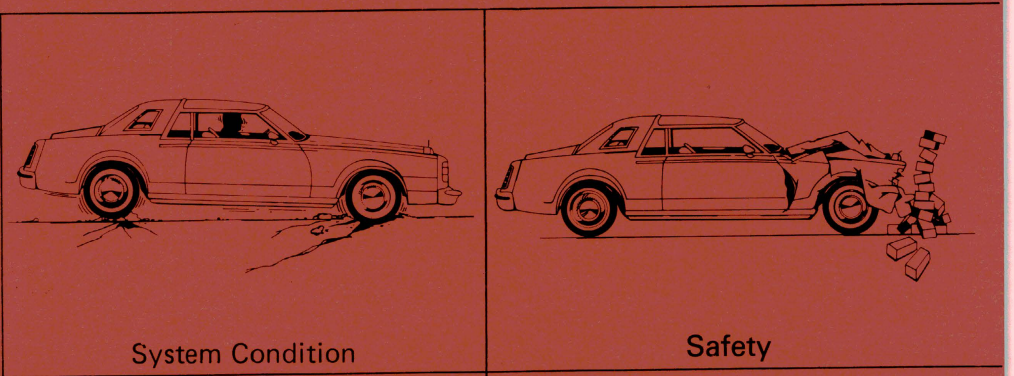
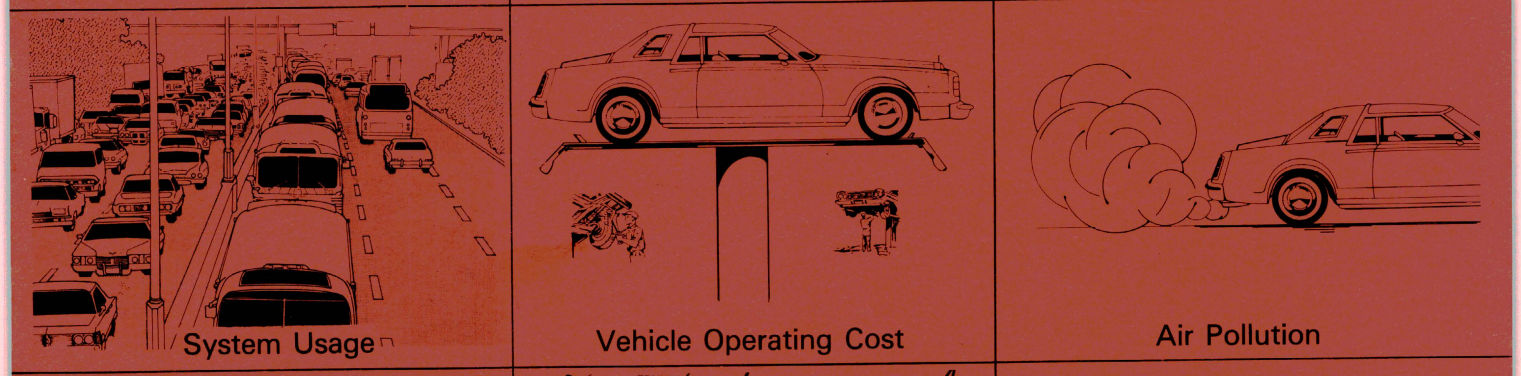
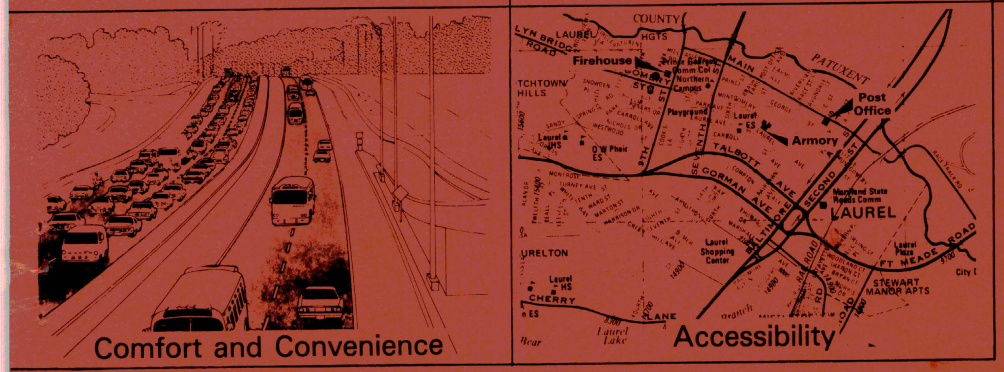
Highway Performance Monitoring System

Phase 1 Report





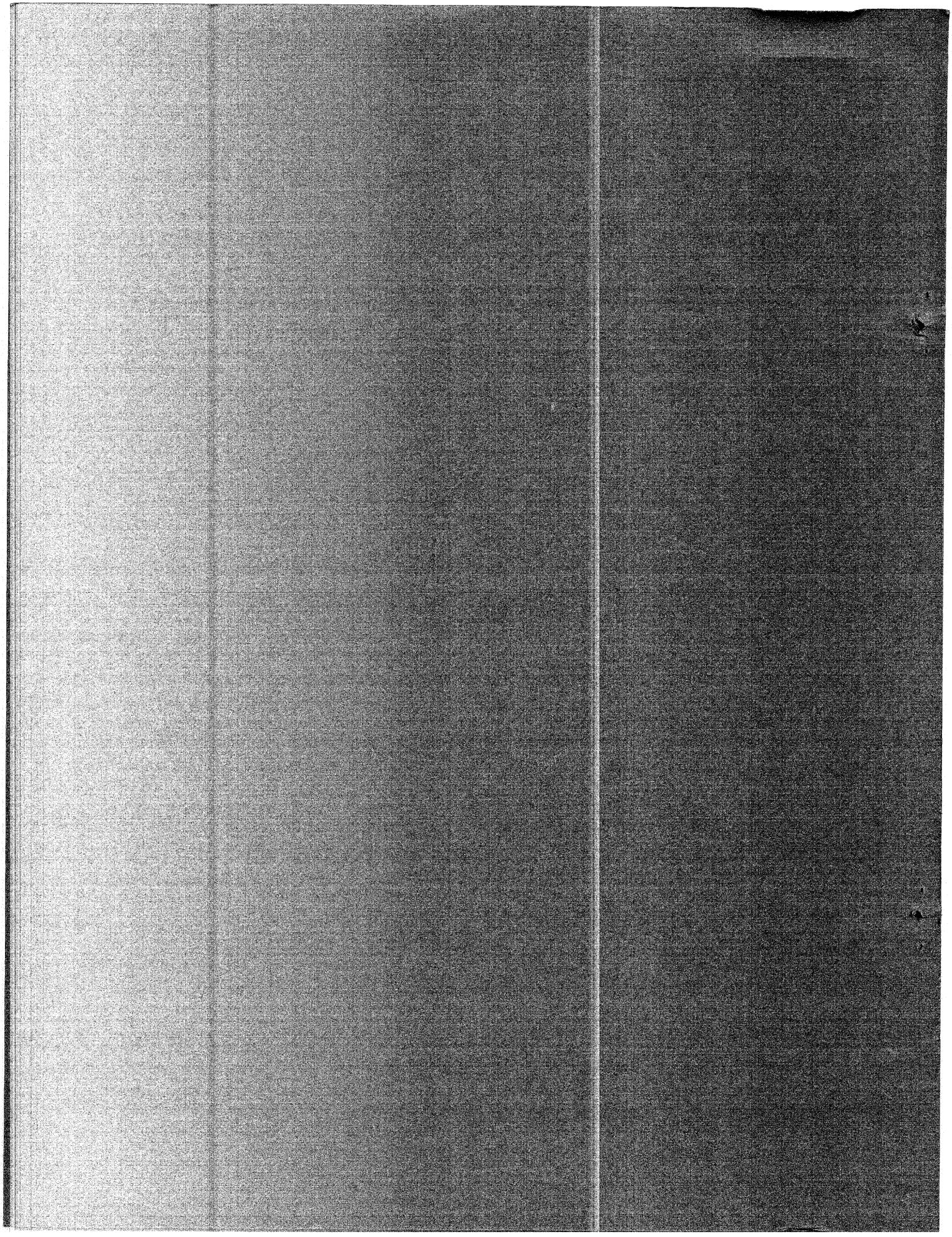


U.S. DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

Program Management Division

September 1978



Highway Performance Monitoring System

Phase I Report

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Program Management Division

September 1978

PREFACE

In recent years, there has been a growing recognition of the need for a mechanism that monitors the performance of our highway system. Such a monitoring system would include the means for obtaining data to assess the highway's capability to provide for the transport of persons and goods and to support the vast expenditure of public funds that are expected to continue to be spent on the Nation's highway transportation system. In 1974, the Federal Highway Administration's (FHWA) Associate Administrator for Planning established a task force to investigate the data and mechanisms needed to measure and monitor highway performance. Further investigation was subsequently undertaken when the task force's recommendation to conduct contract research in highway performance monitoring (more specifically, the extent of data needs and statistical sampling alternatives) was implemented. In May 1977, FHWA's Director of Highway Planning requested that the Program Management Division establish a study group to determine the methods and data needs of monitoring highway performance.

Highway performance monitoring is essential in determining the effectiveness of current highway programs, the possible modifications needed to such programs, the need for new programs, and the most efficient and practical use of dwindling financial resources. A process that provides continuous monitoring of the effectiveness of existing policies and practices is prerequisite to sound State and FHWA highway programs. As a program management tool, a highway performance monitoring system ensures the efficient use of available financial resources and provides invaluable information to decisionmakers.

In the past, limited highway performance evaluations have been made at the national level on a biennial basis as part of the continuing reports required by Congress on highway needs. In a less formalized sense, analytical reviews of programs are being continually undertaken as part of the policy planning function.

As part of the effort to conduct research and to determine the feasibility of a performance monitoring system, the study group has defined practical limits, established common definitions, and identified the types of performance measures and impacts that need to be monitored, the method of monitoring, and the input data for this methodology. Major objectives of this effort are to minimize the need for special national studies such as the "National Highway Inventory and Performance Study" and to develop a highway performance monitoring mechanism that can serve a wide variety of Federal, State, and local planning needs. Such objectives can be met by continuously monitoring a select set of data elements on a controlled sample of highway segments. Wherever practical, the results of existing data collection activities are proposed for use in the monitoring process, either "as is" or in a modified form.

It is anticipated that the State's overall effort for furnishing such data to the U.S. Department of Transportation (DOT) will be redirected to provide data at a reduced level of effort.

The development of the Highway Performance Monitoring System (HPMS) will be based on a four-phased effort: (1) study design (conceptual framework); (2) development of technical procedures; (3) final design and implementation procedures; and (4) analytical procedures development and documentation. Phases 1 and 2 are research-oriented and, as such, involve explorations of alternatives concerning a host of potential performance monitoring system decisions. Many critical areas will be evaluated based on the findings of Phase 2 and decisions will then be made regarding the future of the HPMS.

TABLE OF CONTENTS

TABLE OF CONTENTS (con.)

LIST OF TABLES

I. INTRODUCTION

Background

In recent years, there has been a growing recognition of the need to periodically assess the highway systems with respect to extent and physical condition; the safety, efficiency, and economy of the systems in serving the movement of goods and people; and the impacts of existing programs and policies. In addition, there is a need to assess the potential impacts of proposed programs, policies, and alternatives.

In 1975, the National Transportation Policy Statement emphasized the importance of total transportation assessment as follows:

> "The Federal government should improve its performance measures in assessing the effectiveness of alternative Federal program and policy options and evaluating the health and progress of the transportation system--even though the diversity in transportation needs and cost of providing services make infeasible the formulation of uniform performance standards for all States and localities."
>
> ". . . improve our information base, measures of performance, cost-benefit methodology and planning and program evaluation capability to respond more efficiently to transportation needs and understand the indirect effects of our actions."

Similarly, the Federal interest was further emphasized in 1976 in the National Highway Transportation Policy Statement which said that the "development, analysis, and evaluation of policy is a process that depends upon the systematic assimilation of relevant information, the formulation of alternative policies, and the evaluation of these alternatives in terms of their likely impact on the transportation system." This "new approach" was again emphasized in November 1977 by the Federal Highway Administrator as a means of giving "a better fix on what our programs are actually buying and the various policy alternatives that are available to sustain a safe, efficient transportation system at differing investment and performance levels."

As early as 1974, a task force was appointed by FHWA's Associate Administrator for Planning to determine what mechanism would be needed to measure and monitor the performance of the highway system and would also be responsive to a variety of technical and policy issues. As a result of the activities of the task force, research was undertaken pertaining to highway system performance and the development and evaluation of alternative procedures that could be used to collect data on the operational status and performance capabilities of the Nation's highways.

Although this research effort addressed certain statistical aspects of sampling highway performance data, the effort also resulted in recognition of the fact that, prior to the development of a sampling plan, a definite need exists to focus on the scope, technical approach, analytical approach, and level of desired geographic detail for an overall monitoring process. The overall process evolving from this study has been named the Highway Performance Monitoring System.

The HPMS is expected to be able to respond to a variety of questions concerning not only such major issues as the determination of State and Federal levels of investment necessary to accomplish alternative objectives, but also to answer questions regarding the effects alternative policy strategies and programs could have on highway performance. Also, the HPMS will allow a quicker, more accurate, and more efficient response to legislative requests regarding highway condition and performance. This efficiency will mean a significant reduction in required manpower and data collection peaking characteristics which have plagued both FHWA and the States in the past, particularly with respect to one-time studies. In order to effectively address such questions, as well as to effect the desired manpower and data reductions, it is essential that a core set of data elements be identified, defined, and decided upon.

The basic philosophy applied in the development of the data needs is that of minimizing or, where feasible, eliminating the requirement for data collection efforts. As the HPMS is being developed, potential revisions to the current highway planning data collection effort at both the State and national levels will be identified, particularly whenever duplicative efforts are discovered.

It is intended that HPMS data be gathered by using statistical sampling techniques and that resampling be controlled by the frequency of statistically significant changes in the individual data items and workload demands. Time-phasing of collection efforts will be a major concern in an effort to avoid periodic, extraordinarily heavy workloads. It is anticipated that the activities related to the implementation of the HPMS will be spread over several years (a cycle), with various portions of the results being reported on perhaps an annual basis.

Purpose

The purpose of the HPMS effort is to investigate, design, develop, document, and implement a continuing system capable of assessing the performance of the highway systems with respect to the safe, efficient, and economical movement of people and goods; to calculate the impacts existing highway programs and policies have on the overall performance of the highway system; and to forecast the potential impacts future alternative highway programs and policies could have on performance. Major considerations in the design of the HPMS include:

- The identification of performance measures and impacts pertinent to policy planning and program evaluation.

- The development of sampling plans and procedures for the collection and monitoring of a reasonable set of data elements, with particular emphasis on maximum use of available data.

- The design, development, and documentation of procedures for translating data into performance measures and for developing impacts from those performance measures.

- The development of a system that can be applied by both the FHWA and individual States.

Objectives

The objectives of the nationwide monitoring system are to establish the capability to periodically assess the extent and condition of the highway systems, to measure the highway systems' performance, and to quantify impacts. A significant portion of the total project resources will be devoted to developing procedures for analyzing the performance results with respect to investment levels and policy issues.

Definitions

Preliminary work revealed that there are extensive semantic problems with the terms being used. Therefore, the following definitions have been developed for this project.

Highway System Performance.--The degree to which the highway system serves the movement of people and goods safely, efficiently, and economically at various points in time (past, present, and future).

Inventory Data Elements.--Measured or estimated data elements describing the highway plant, e.g., condition, mileage, number of lanes, lane width, etc., and usage of the plant, e.g., average daily traffic (ADT), fatalities, tons of freight, vehicle occupancy, etc.

(While most of these data elements cannot be considered to be performance measures, extent and usage data are a vital part of highway performance. For example, miles of highways in various states of physical condition, when coupled with usage information, become very important and heavily used performance measures.)

Performance Measure.--An item of information that is a function of both the highway physical plant and its usage as measured at a given point in time. (Performance Measure = f(inventory data elements, other physical attributes, usage data)). Examples of performance measures are:

1977 Vehicle-Miles Traveled (VMT) on deficient pavement
1977 Speed
1977 Accident Rates

Impact.--The change in a performance measure between two points in time. Figure 1, Determination of Impacts, illustrates this definition by showing how, for a specific performance measure such as traveltime, the impacts for an existing and three future alternative policies are determined.

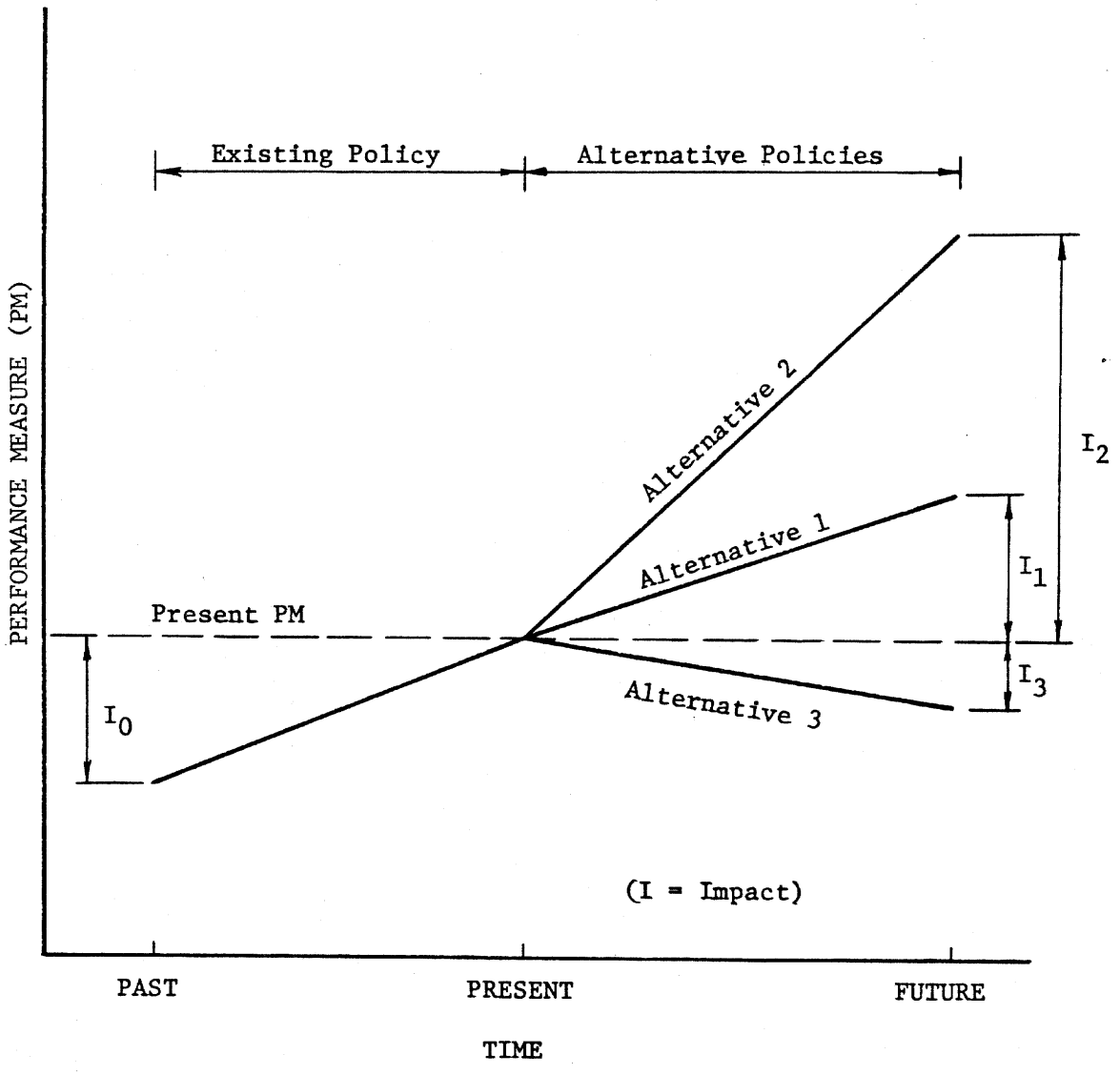


Figure 1. Determination of Impacts

Scope

Geographic Detail

The HPMS design must be capable of producing valid estimates of the condition of the highway plant, its operating characteristics, and its performance characteristics on a State-by-State basis. A national sample, or a sample of several States, would not be responsive to questions regarding the level of treatment that individual States and various regions of the country have been receiving or could receive under a given policy proposal alternative and, therefore, would be inadequate. There is a large variation from State to State in problems, revenues, ADTs, jurisdictional considerations, system extent, condition, performance, etc.; therefore, it is felt that certain base data must be collected in each State. This position is supported by the fact that many congressional and DOT/FHWA policy requests are related to individual State data. For these reasons, sample data will be required for rural, small urban, and urbanized areas within each State.

Other information, such as fuel consumption rate relationships, will be developed by FHWA by means of contract research--in some instances, certain data may be collected as case studies and applied nationwide. The specific data items that will comprise the base data, that will be developed through research or that will be collected by case studies are discussed in detail in Cahpter III.

Urban and Rural Areas.--Within each State, independent urban and rural analyses must be made so that programs that are unique to urban or rural areas can be properly assessed. In addition, travel and physical characteristics of the highway plant differ considerably in urban and rural areas and, perhaps, different performance measures will be applicable.

Urbanized Areas.--Independent appraisals of highway system performance for each urbanized area must be made because of the individuality that exists in urbanized areas. There is now no regular mechanism for reporting data by individual urbanized area; however, experience with national studies has indicated a continual demand for individual urbanized area transportation statistics. Accordingly, a basic minimum data set will be gathered for each urbanized area. Perhaps supplemental data will be gathered for areas with large populations, particularly above 200,000, where Federal funding considerations are most important.

Base Systems for Analysis

Federal-aid, functional, jurisdictional, and administrative systems were all considered as the possible base for the HPMS. Federal-aid systems initially appeared to be a logical base except that these

systems, because of program funding considerations, may not remain fixed over time and are, by law, based on the functionally classified systems. State jurisdictional and administrative systems vary widely and, in aggregate, do not form a uniform system; therefore, these also were rejected. For these reasons, the functional systems required by Title 23 have been chosen as the most logical permanent base for HPMS. It is recognized that, because of spreading urbanization and because of the changing traffic patterns resulting from the construction of new facilities, the HPMS must accommodate future revisions to these functionally classified systems.

All functional systems will be monitored to some extent. However, since the Federal interest in local roads is considerably different from that in higher functional systems, less data will be gathered for local roads and that data will be gathered less often.

Urban Boundaries

Federal-aid urban area boundaries (as defined in Section 101(a) of Title 23) were chosen for use in the HPMS effort because they were all derived using the same basic definition, and they should remain fixed for some extended period of time. Also, Federal-aid urban boundaries, by definition, are the termini of unique urban and rural Federal-aid highway programs.

Data and Information Framework

Development of the capability to periodically measure the performance of the highway plant, the quantification of changes therein, and the assessment of the impacts associated with such changes must be based on valid, representative data and information. These data and information needs logically can be satisfied by a variety of sources and schemes. In an effort to identify the most logical and practical solution, Phase I of the HPMS study has included a review and evaluation of all relevant existing data sources within DOT with an eye toward their potential input into the highway performance monitoring process. This basically was accomplished by a series of about 30 "ministudies" that scrutinized existing data sources, explored ongoing and anticipated research, and examined any attempts to modify existing data collection procedures or to implement new requirements.

Preliminary assessments of HPMS data and information needs were reviewed in detail to determine the most practical approach to filling these needs. The following hierarchy was used in making this determination:

1. Existing data sources (reporting systems).
2. Revisions to existing reporting procedures.
3. New data reporting systems (e.g., Urban Mass Transportation Administration (UMTA) uniform system of accounts and records (FARE) system).

4. Ongoing, as well as planned, contract research.
5. FHWA in-house projects designed to meet specific HPMS needs.
6. New contract research specifically designed to meet certain HPMS needs.
7. State highway agency data that will be reported periodically based on practical time-phased implementation schedules.

II. ASSESSMENT OF IMPACTS

An immediate objective of the HPMS is to establish the framework for the assessment of highway system performance and impacts. Specific impact areas were selected based upon present and anticipated areas of national concern as related to highway transportation.

In the process of identifying and selecting the impacts, it became evident that there are not only direct impacts but also there are a number of indirect or secondary impacts that result from the process by which current and potential highway users adjust to changes in performance. Consideration of these indirect impacts is to take place at a later date after information about the direct impacts has been obtained. It should be noted that the impact and other calculations will be performed by FHWA using analytical models and sampled data.

There were seven direct impacts identified for assessment: system condition, system usage, safety, comfort and convenience, vehicle operating cost, accessibility, and air pollution.

System Condition

System condition is the condition of the pavement, bridges, and other structural components of the highway. It is the most important impact that has been identified for assessment within the performance monitoring concept. This impact has been a primary subject of past legislation and is a primary concern of planners everywhere. In order to develop this impact, such factors as miles, lane miles, and vehicle miles of travel per lane mile by pavement type and condition will be derived. These quantities, along with the number of deficient bridges and other condition indexes, will be used in determining system condition.

System Usage

System usage is a measure of the service that the various functional systems provide in terms of moving people and goods. Highway system usage data are fundamental to all appraisal and evaluation processes and are essential inputs to the assessment of the service various systems and alternative policies and programs provide. This impact, then, is an accountability measure for continuing investment in highway construction and improvement programs and, as such, serves in the overall evaluation of the effectiveness of such programs.

Safety

The safety impact area is concerned with the property damage, injury, and fatality occurrences and costs associated with highway accidents. The effectiveness of policies and programs with respect to accident reduction, lives saved, and economic loss avoided must be evaluated and quantified and given proper consideration in the decisionmaking process. Safety-related data are also a prerequisite for the evaluation of the effectiveness of existing programs and policies and for forecasts of the potential consequences of future alternative policy and program proposals, including the continuation of existing policies and programs. Accident rates and costs also play a significant role in cost-benefit and cost-effectiveness analyses.

Comfort and Convenience

Comfort and convenience is a measure of adverse driving conditions that might cause increased emotional stress. Adverse driving conditions resulting from poor riding qualities of the roadway surfaces, extreme alignment deficiencies, and traffic congestion resulting in delays, conflicts, and numerous speed changes are to be considered. The anxiety experienced by the motoring public under adverse driving conditions is a health hazard in every sense and, more importantly, is a significant contributor to highway accidents. Various factors, including those mentioned above, contribute to the highway user's diversion to other routes even at the expense of increased travel distance and/or time. Comfort and convenience, although they are nebulous, unquantifiable factors, are nonetheless real and will be addressed.

Vehicle Operating Cost

Vehicle operating cost information, consisting of the costs of fuel consumption, tires, oil, maintenance, and use-related depreciation, is a primary consideration because it is a direct measure of costs incurred and perceived by the highway user. In addition, vehicle operating costs represent a comprehensive measure of the overall efficiency of the highway systems since it reflects the effects of vehicle operating characteristics, engine fuel efficiency, roadway geometry, traffic operating conditions, and the overall physical condition of the highway plant. Vehicle operating costs serve a vital role in a number of important analyses, including user-benefit, cost-benefit, and cost-effectiveness analyses.

Accessibility

Accessibility is a measure of change in traveltime (transporting people and goods from one place to another via the highway system) and/or vehicle operating cost. Chiefly among the indicators of accessibility is traveltime, which typically is used as a measure of the effectiveness of traffic management programs. Accessibility will be addressed as a subjective function of the changes in traveltime and vehicle operating cost as well as in an index form that takes geographic location into consideration.

Air Pollution

Air pollution is the highway vehicle emission of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x) that contributes to the degradation of air quality. Although difficult to quantify but decidedly real, this impact emphasizes a commitment to improvements in overall air quality. Comprehensive analyses of air quality impacts of highway travel will not be undertaken by the HPMS because of extensive data required to do so. However, less sophisticated macro-estimates of tons of emissions of CO, HC, and NO_x produced will be made.

III. ALTERNATIVE PERFORMANCE MEASURE AND DATA ASSEMBLY OPTIONS

Much of the data needed for a performance monitoring system is already being collected. A basic problem over the years, however, has been that many data collection activities, both one-time studies and continuing reporting mechanisms, have lacked coordination among the activities. In a effort to eliminate this situation and to optimize data collection efforts and utility, five options were developed with particular regard to the data needed.

The options developed cover the range of data collection intensity varying from an available data option to the most comprehensive data collection option. The available data option would require no additional data to be collected beyond that already being reported. The primary sources of available data would be the Mileage Facilities Reporting System and other existing series reported to the Federal Highway Administration.

The remaining options were developed in a building block fashion in that each successive option's data collection requirements were based upon the data collection requirements of its predecessor. With an incremental increase in data collection activity beyond the preceding option's data requirements, performance measures and impact assessments were continuously improved and refined.

The five alternative approaches or levels of data intensity that were developed are:

1. Available Data Option.--No additional data elements would be collected. Only that data collected as of December 1977 would continue to be reported for future use.

2. Implemented Mileage Facilities Reporting System (MFRS) Option.--No additional data would be collected other than that which is presently proposed to be collected by the FHWA Highway Statistics Division through the fully implemented MFRS and revised financial data requirements.

3. Augmented MFRS Option.--In addition to the data that would be available through the second level, collect only critical data elements and conduct high priority research associated with this option.

4. Constrained MFRS Expansion Option.--Supplement existing data, including that available through the MFRS, with a minimum data set that would provide the desired level of impact and performance assessment. Conduct all research identified as high priority for this option.

5. Comprehensive MFRS Expansion Option.--Collect all necessary data to directly quantify and assess all of the desired performance measures and impacts.

Available Data Option

Existing Data Sources

The Available Data Option is concerned only with existing data sources, and no additional data elements are to be collected. The following individual sources of data are currently available:

Mileage Facility Reporting System (MFRS).--The MFRS conceptually represents FHWA's framework for a mileage-based integrated data base management system. This system was initially designed to meet certain administrative and technical data needs, but the MFRS recently underwent further development when it was proposed that TA-1 accident/travel data become part of the integrated data base.

Because the MFRS is in the early stages of development and implementation, it cannot be expected to provide data that are sufficiently comprehensive and/or responsive to anticipated HPMS needs. (Anticipated use of a more fully developed and implemented MFRS is explored in subsequent options.) It is important to note that without the MFRS, there is no continuing source of functional classification and urbanized area data.

Highway Statistics.--This data source is a general collection of a myriad of existing reporting forms which are periodically supplied to FHWA. The information gathered in this manner includes extensive mileage, motor fuel, motor vehicle, driver licensing, highway usage characteristics, and finance data. These data, however, have some features that hinder their direct use in monitoring performance. For instance, individual tables present different details that are not interrelated and data are not always presented in a consistent manner. Without these consistencies and interrelationships, performance cannot be successfully monitored.

Another problem area relates to the definition of "municipal" and "urban." The term "municipal" is not synonymous with "urban" and varies from State to State. While urban is normally defined as Federal-aid urban, there is no separation of small urban and urbanized information, and this definition is normally used only with Federal-aid system discussions.

Motor fuel, motor-vehicle taxes and revenues, vehicle registration, and driver licenses data are considerably more useful. Financial expenditure data are available in aggregate form but are not available by functional classification, improvement type, or individual urbanized area.

Table TA-1.--This table provides statewide information on mileage, vehicles per day, travel, fatalities, fatal accidents, nonfatal injuries, and nonfatal injury accidents by Federal-aid and generalized functional system--arterial, collector, and local. Rural-urban and full control of access breakdowns are provided; accident information is presented in both number and rate form.

The above data presently allows State-by-State comparisons of rate information on a Federal-aid and other State and local road basis. However, there are no property-damage-only accident rate, detailed functional system, design type, or well-defined geographic location data available.

Fatal Accident Reporting System (FARS).--This National Highway Traffic Safety Administration (NHTSA) system provides data on fatal accidents for rural and urban areas within each State. However, not only does it not provide information on other types of accidents, the traffic volumes associated with the accidents, access control, and functional system, but also the accuracy of the data describing the conditions related to the accident is questionable. There is also a difference in the definition of a fatality between this source and Table TA-1.

Truck Weight Study (TWS).--This source of information provides vehicle classification data on an annual basis and truck weight data every other year with approximately half the States reporting each year.

There are several difficulties in using data from this source. First, the proportion of trucks in the classified traffic stream is higher than the overall average because the stations are located on routes that have heavy truck usage. Secondly, there is a limited number of urban stations. And finally, there is significant weight information available only for the summer months.

Nationwide Personal Transportation Study (NPTS).--This study was conducted by the Bureau of the Census, Department of Commerce, for FHWA in 1969-70. This survey made it possible to relate household socio-economic and location characteristics to daily travel characteristics for all modes, but only for nationwide statistics.

The NPTS was merged with the National Travel Survey (NTS) in 1977 and, therefore, is part of the 1977 Census of Transportation. Resultant data are in aggregate areawide form for various levels of geographic detail. No information on functional classification is provided. These efforts will provide useful national background information but will provide no State or section specific information.

Automatic Traffic Recorder Data (ATR).--There are presently 45 States submitting hourly traffic volume data on computer tape for some 4,085 permanent ATR counter locations nationwide. Due to technical problems, particularly the collection of data in winter months, only 3,000 are supplied for more than 9 months of the year.

Each counter site reported is identified by route, location, and highway class. Until such time that the identification information can be expanded to include functional classification and other physical characteristics, these data will not be very useful in performance monitoring.

Structure Inventory and Appraisal of the Nation's Bridges.--Under the National Bridge Inspection Standard (NBIS) inventory program, all bridges on the Federal-aid systems are inventoried, inspected, and appraised by the States. The first NBIS inventory was begun in July 1972 with the most recent update required as of December 1, 1977. These data now include functional classification as well as city and county codes.

National Highway-Railroad Crossing Inventory.--This inventory contains up-to-date information for each crossing. The functional classification of the highway is identified, but the Federal-aid rural, small urban, or urbanized area designation is not included.

Other Data Sources.--Four other data sources were examined and were found to be deficient to the extent that they were excluded from the monitoring process. These sources and a major deficiency for each are:

- 55 M.P.H. Speed Monitoring Studies.--Collected only on those segments having a 55 m.p.h. speed limit.

- Truck Inventory and Use Survey (Bureau of the Census).--Is a probability sample collected every 5 years and is not reliable at less than multi-State area levels.

- Land Area and Population (Bureau of the Census).--Contains no Federal-aid urban or urbanized area statistics.

- Project Status Record (PR-37).--Excludes non-Federal-aid projects.

Possible Performance Measures

Before discussing performance measures that can be derived from existing data, it is necessary to make the point that one can develop estimates of practically anything by using existing data and by making a series of assumptions. However, the results will be only as good as the input data and the assumptions made. With this thought in mind, performance measures for this option were limited to those that can be derived from reasonably sound data and that require few assumptions.

The key to calculating performance measures for any system within a geographic area is to know the mileage distribution of highway types and, within each of these highway types, the mileage distribution by ADT range. Also, sufficient roadway data are needed to derive capacity and speed (traveltime). However, some of the key elements are missing. Notably under this option, financial, mileage, and travel controls would be very weak and would be limited to State totals by Federal-aid systems--the lack of system condition data is a major deficiency. On the other hand, the available bridge (Federal-aid systems only) and railroad crossing data are good and will need no revision.

By using only available data, estimates cannot be made of vehicle operating cost, traveltime, air pollution, and comfort and convenience. The safety impact area is the most complete area in that published aggregate accident rates are available for Federal-aid systems as well as arterial, collector, and local classes (TA-1 Table). For the system usage and vehicle operating cost impact areas, the indicated performance measures are weak at best and, over time, will be of extremely limited value. The only estimate possible under this option for accessibility is a mileage density measure that will change very little over time. In fact, this estimate is not a performance measure by HPMS definition. Table 1 contains a list of the performance measures that can be estimated under this option.

TABLE 1

IMPACTS AND ASSOCIATED PERFORMANCE MEASURES

Available Data Option

Impacts	Performance Measures
System Condition	Miles by Pavement Type: 1. National by Federal-aid, State, and Local 2. By State - surfaced FAP mileage by surfaced type and width Number of Deficient Bridges (Federal-aid systems only)
System Usage	VMT/Lane-Mile (FAP and FAU only) Auto Occupancy (National) Truck Ton-Miles (National)
Safety	Fatalities/10^8 VMT Injuries (All nonfatal)/10^8 VMT Fatal Accidents/10^8 VMT Nonfatal Injury Accidents/10^8 VMT (By Table TA-1 breakdowns - Federal-aid system and other)
Comfort and Convenience	Little or nothing possible
Vehicle Operating Costs	Miles/Gallon by Vehicle Type (National) Gallons/1,000 VMT by State (Highway statistics) Miles/Gallon by State (Highway statistics)
Accessibility	Miles/Square Mile by State
Air Pollution	Little or nothing possible

Implemented MFRS Option

Existing Data Sources

The majority of existing data sources are the same as those presented in the Available Data Option, and it is assumed that the majority of States will be reporting section-by-section data through MFRS in the established form and that the financial data reporting requirements of the FHWA Highway Statistics Division will be revised to reflect HPMS needs. The only new data source available under this option is the NHTSA National Accident Sampling System (NASS).

The implemented MFRS represents a major step forward by providing control totals for mileage and VMT by functional, Federal-aid, and administrative systems for rural, small urban, and individual urbanized areas.

The financial reporting requirements will provide Federal-aid and non-Federal-aid project capital expenditures for rural, small urban, and individual urbanized area by functional, Federal-aid, and administrative systems, and by improvement type. Problems associated with implementing such requirements include obtaining data for individual urbanized areas as well as 100-percent State and local project financial data. Transition concessions may be inevitable until the States can provide the necessary input.

NHTSA's NASS program consists of very detailed investigative analyses of a small sample of accidents in 10 sample areas beginning in 1978. Results of this program will enable accident rate information to be improved.

Possible Performance Measures

Using the implemented MFRS as the primary data source, the following data and information become available on a section-by-section basis.

- Population
- Access control
- ADT
- ROW width
- Shoulder type
- Pavement type
- Pavement width
- Number of lanes
- Median type
- Section length

These data define the design type, ADT, and number of lanes on the sections, thereby permitting the estimation of capacities.

Table 2 contains performance measures possible under this option. Without additional information, e.g., speed-related information, no improvement can be made over the Available Data Option in the safety, accessibility, and air pollution impact assessments. However, these data improve performance measure capabilities in the system condition, system usage, and comfort and convenience areas.

TABLE 2

IMPACTS AND ASSOCIATED PERFORMANCE MEASURES

Implemented MFRS Option
(No New Data Collection, MFRS Fully Implemented,
and Financial Reporting Requirement Revised)

Impacts	Performance Measures
System Condition	Miles by Pavement Type Lane-Miles by Pavement Type VMT/Lane-Mile by Pavement Type Number of Deficient Bridges (Federal-aid systems only)
System Usage	VMT/Capacity-Mile (Peak and off-peak) Auto Occupancy (National) Truck Ton-Miles (National)
Safety	Fatalities/10^8 VMT Injuries (All nonfatal)/10^8 VMT Fatal Accidents/10^8 VMT Nonfatal Injury Accidents/10^8 VMT (By Table TA-1 breakdowns - Federal-aid system and other)
Comfort and Convenience	Percent VMT versus V/C (Overall travel speed in urban areas) Percent VMT with Full, Partial, or No Access Control Percent VMT on Divided and Undivided Highways
Vehicle Operating Costs	Miles/Gallon by Vehicle Type (National) Gallons/1,000 VMT by State (Highway statistics) Miles/Gallon by State (Highway statistics)
Accessibility	Miles/Square Mile by State
Air Pollution	Little or nothing possible

Under this option, needed financial, mileage, and VMT data will be available from the FHWA Highway Statistics Division.

Augmented MFRS Option

High Priority Research

This option is an expansion of the Implemented MFRS Option and existing data sources are the same as in the first two options. However, there would be a need to conduct several high priority research activities such as defining the relationships between pavement type and pavement condition, updating vehicle operating cost and fuel consumption rate tables, providing statistical guidance and analysis in establishing sample designs, etc. These research activities would be conducted through either in-house FHWA efforts or the FHWA contract research program and would not require additional field efforts.

This option would also require that certain revisions will be made to the existing MFRS instructions and guides to clarify and expand upon existing definitions, and certain additional critical data elements would be collected for a "fixed panel" of sections. The "fixed panel" or subpanel of sections would be randomly selected by the SHAs.

The concept of a "fixed panel" of sections (discussed in more detail in Chapter IV) involves the monitoring of key highway facility, condition, and usage data on the same sample of sections from year-to-year or another cycle basis. This approach is in lieu of selecting a new sample of sections each cycle. It assures more statistically valid comparisons of performance measures over time (impact assessment) and will contribute to long-range economies. In spite of the term "fixed panel," the concept will be required to reflect changes, such as new facilities and changing urban boundaries.

Critical Data Elements

In a critical data requirement sense, only one MFRS data element needs revision--shoulder width. Shoulder widths of less than 6 feet have an important role in safety considerations and have a direct impact on highway capacity; therefore, this item must be revised to reflect shoulder widths to the nearest foot for those shoulders less than 6 feet wide.

The following data elements are considered to be critical to the successful monitoring of system performance and would need to be added to the MFRS data elements:

- Number of Curves.--The number of curves is critical in the determination of the average highway speed (AHS) or weighted design speed that, in turn, is critical in the derivation of running speed.

- Speed Limit.--This data element, like AHS, is critical in the determination of speeds.

- Percent of Length with Passing Sight Distance ≥ 1,500 Feet.--This is critical in the determination of speed on two-lane rural roads.

- Pavement Condition.--This is an essential HPMS input in determining system condition.

- Percent Trucks.--This data element is essential to capacity derivation.

- Percent Green Time.--For signalized facilities, this is critical for determining a roadway's capacity.

- Terrain.--In rural areas, terrain is critical in the determination of capacity.

- Number of Intersections.--The number of intersections that are signalized, or otherwise controlled, is critical in the determination of speed, vehicle operating cost, and accessibility, particularly in urban areas.

- Parking.--Parking arrangements for peak and off-peak periods are critical in the determination of a street's capacity.

- Urban Location.--The location of a section within an urbanized area significantly affects the capacity of the section.

- "K" Factor.--This factor is essential in the classification of a section with respect to peak-hour performance.

- Vehicle Classification.--This is necessary in order to determine the performance measures for the system usage, safety, vehicle operating cost, and air pollution impact areas.

- Improvement Type and Capital Cost of Improvement.--These data will permit analyses of the type of improvement, capital cost of improvement, and the change in the physical and operational characteristics of the highway section with regard to return on investment.

Possible Performance Measures

Table 3 contains a list of the possible performance measures that can be developed under this option.

TABLE 3

IMPACTS AND ASSOCIATED PERFORMANCE MEASURES

Augmented MFRS Option

Conduct High Priority Research and Collect Only Critical Data Elements

Impacts	Performance Measures
System Condition	Miles by Pavement Type and Condition Lane-Miles by Pavement Type and Condition VMT/Lane-Mile by Pavement Type and Condition Number of Deficient Bridges (Federal-aid systems only) Various Physical Condition Deficiency Indexes
System Usage	VMT/Capacity-Mile (Peak and off-peak) Auto Occupancy (National) Truck Ton-Miles (National)
Safety	Fatalities/10^8 VMT Injuries/10^8 VMT (Includes fatalities) Nonfatal Injuries/10^8 VMT Fatal Accidents (Number and cost)/10^8 VMT Nonfatal Injury Accidents (Number and cost)/10^8 VMT Property-Damage-Only Accidents (Number and cost)/10^8 VMT
Comfort and Convenience	Percent VMT versus V/C (Overall travel speed in urban areas) Percent VMT on Deficient Highways by Pavement Type Percent Trucks and Buses Percent VMT on Inadequate Horizontal and Vertical Curvature Percent VMT on Narrow Lane Roads Percent VMT with Full, Partial, or No Access Control Percent VMT on Divided and Undivided Highways
Vehicle Operating Costs (VOC)	VOC ($)/1,000 VMT (Overall, peak, and off-peak) VOC ($)/1,000 VMT by Vehicle Type VOC ($)/1,000 VMT by Design Type and Pavement Type and Condition Gallons/1,000 VMT by Fuel Type (Overall, peak, and off-peak) Gallons/1,000 VMT by Vehicle Type
Accessibility	Accessibility = Subjective Function of Changes in Traveltime and Vehicle Operating Cost Impacts Accessibility Index = f (Changes in traveltime and vehicle operating cost impacts) (Hours or $)/1,000 VMT (Overall, peak, and off-peak) (Hours or $)/1,000 VMT by Vehicle Type (Hours or $)/1,000 VMT by Design Type and Pavement Type and Condition Congestion Index = Peak (Hours/VMT) ÷ Off-Peak (Hours/VMT) Delay Index = Percent Traveltime in Delay Mode (Peak and off-peak)
Air Pollution	CO, HC, and NO_x Tons/10^6 VMT (Overall, peak, and off-peak) CO, HC, and NO_x Tons/10^6 VMT by Vehicle Type

Constrained MFRS Expansion Option

Necessary Research

Over and above the effort required in the Augmented MFRS Option, this option would require that the following additional research be conducted by FHWA:

- Develop procedures for obtaining adequate vehicle occupancy information.
- Develop procedures for obtaining truck weight and load factor information.
- Develop a plan for evaluating exclusive bus and high occupancy vehicle lanes/roadways.
- Develop a plan for obtaining areawide bus usage information.
- Identify pertinent types of roadside development.
- Develop a plan for relating gross sample data on bridges and railroad grade crossings to available comprehensive data on bridges and railroad crossings.

Critical Data Elements

This option requires that additional revisions be made to the existing MFRS in order to clarify and expand upon current definitions. Additional data elements also need to be added to supplement that which is already available. Table 4 contains an itemized list of the HPMS data needs under this option exclusive of research needs.

The following list includes data items requiring revision beyond those suggested in the preceding option:

- Land area and population for rural, small urban, and individual urbanized areas must be obtained from the States. These data would be used in the accessibility analysis process.
- Data on median type, median width, and type of operation are presently inadequately reported as part of the MFRS "median type" data item. Median type must provide a description of the median and median width must define the prevailing width to the nearest foot. Both data elements are necessary to assess the operational and safety aspects of the roadways. Peak and off-peak type of operation would provide information needed to define capacity.

TABLE 4

CONSTRAINED MFRS EXPANSION OPTION
HPMS DATA NEEDS (Other Than Research)

Data Item	Present Source	Acceptability of Source		Remarks
		As Is	Modified	
No. of Lanes	MFRS[1]	Yes		Includes no. of through lanes only.
Access Control	MFRS	Yes		
Median Type	MFRS	No	Yes	All three items are contained in "Median Type," which must be revised to separate types of data and provide more information.
Median Width	MFRS	No	Yes	
Type of Operation	MFRS	No	Yes	
Section Length	MFRS	Yes		Must be confined to homogeneous physical and operational characteristics.
Grades	None	No	No	
Curves	None	No	No	
Pavement Type	MFRS	Yes		Too detailed, aggregate data to meet needs.
Pavement Condition	None	No	No	
No. of Intersections	None	No	No	
At-Grade RR Crossings	NHRCI[2]	Yes		Data identified by FA and functional systems. Done before recent FA system realignment.
No. of Bridges by Type of Deficiency	NBIS	Yes		Data available for FA systems, but lacking for off-system and rural minor collectors.
ADT	MFRS	Yes		
% Trucks	TWS	No	No	Too biased-counts are taken on truck routes.
Parking	None	No	No	
Speed Limit	None	No	No	
% Passing Sight Dist.	None	No	No	
Terrain	None	No	No	
Lane Width	MFRS	Yes		
Shoulder Type	MFRS	No	Yes	Both are in "Shoulder" and need better definition, e.g., type may be none, stone, paved, etc.
Shoulder Width	MFRS	No	Yes	
Approach Width	MFRS	Yes		Pavement width.
% Green Time	None	No	No	
Pop. Size Code	MFRS	Yes		
Urban Location	None	No	No	
"K" Factor	None	No	No	
"D" Factor	None	No	No	
Type of Development	None	No	No	
ROW Width	MFRS	Yes		
Skid Resistance	None	No	No	
Federal-aid System	MFRS	Yes		Must deal with travel and designated way breakdowns.
Functional Class.	MFRS	Yes		
Jurisdiction	MFRS	Yes		Governmental level of control.
Improvement Type	None	No	No	
Imprvmnt. Cap. Cost	None	No	No	
Drainage Condition	None	No	No	
Daily Veh. Type. Dist.	None	No	No	TWS data is biased, and does not give daily dist.
Occupancy - Veh. Type	NPTS	No	No	
Avg. Load - Trk. Type	TWS	No	No	TWS data is biased, and is not representative.
Bus PMT	FARE	No	No	Areawide control totals.
Capital Cost	HS[3]	Yes		Control total.
Maintenance Cost	HS	No	Yes	Estimated control total.
Mileage	MFRS	Yes		Control total.
VMT	MFRS	Yes		Control total.
Land Area	Census	No	Yes	General information.
Population	Census	No	Yes	General information.
Licensed Drivers	HS	Yes		General information.
Registered Vehicles	HS	Yes		General information.
Revenues	HS	Yes		General information.
Speed	None	No	No	Measured values used for calibration.
Traveltime	None	No	No	Measured values used for calibration.

NOTES:

[1] Presumes complete recording of MFRS individual section specific information with "unknown" codes eliminated.

[2] National Highway-Railroad Crossing Inventory

[3] Highway Statistics

- Vehicle classification data are necessary to determine representative vehicle type distributions by time of day to permit analysis of performance.

- Horizontal alinement data would include not only the number of curves but also the length of individual curves. These data would be used in the analysis of safety, comfort and convenience, vehicle operating cost, accessibility, and air pollution.

Additional data elements required beyond those identified in the preceding options are:

- Both railroad crossing and bridge identification numbers would be obtained in order to access information from the existing sources.

- Type of control at intersections, e.g., none, stop sign, or signalized (nonprogressive, progressive, or traffic actuated), would facilitate improved estimates of traveltime and capacity.

- Shoulder information would include type and width. Shoulders should be classified by none, paved, gravel, and grass, and width should be reported to the nearest foot. Both data elements are important in calculating capacity and in the evaluation of safety performance measures.

- "D" factor, directional factor, would be necessary to assess congestion and speed on facilities with imbalanced traffic flow.

- Type of roadside development would be added as a parameter for comfort and convenience performance measures.

- Vertical alinement data are required to further refine the performance measures for safety, comfort and convenience, vehicle operating cost, accessibility, and air pollution.

- Skid resistance data would be added in order to address safety issues.

- Drainage adequacy would be added to permit application of various models concerned with needs/investment levels.

- Vehicle occupancy data would allow performance assessment in terms of person miles of travel (PMT)--a meaningful indicator of the service provided by highways. Vehicle occupancy also provides a means of assessing energy efficiency and air quality improvement programs.

- Total bus PMT by scheduled intercity, school, and transit categories would need to be obtained on an areawide basis.
- Average carried load, by truck type, would be required to enable quantification of total ton-miles of freight carried and to provide a means of assessing relative freight movements among systems.
- Maintenance cost control estimates by geographic area and functional system would be added under this option.
- A representative number of speeds (traveltimes) would be measured to establish and/or control traveltime prediction relationships for use in estimating speeds (traveltimes) on the remaining sections.

Possible Performance Measures

Table 5 contains a list of possible performance measures that can be developed under this option.

Comprehensive MFRS Expansion Option

Improvements beyond the preceding options can be made in two ways--by improving the quality of performance measures and by providing additional performance measures. Either method of improvement will require additional data with associated increase in collection effort and cost.

Improved Performance Measures

To improve general performance measure capabilities, ADTs, capacities, speeds, vehicle weights, vehicle type distributions, freight movement, and vehicle occupancy data must be improved. ADT would be improved by obtaining permanent automatic traffic recorder data for a representative sample of the fixed panel of sections. Vehicle type distribution, weight (including auto weight), and occupancy information would be collected at these same locations. To improve urban capacity, additional information on left and right turns and number of transit buses per hour would be obtained in urban areas on a section-by-section basis. To improve speed or traveltime, more independent variables would be included and more measurements would be made, thereby adjusting estimating relationships.

TABLE 5

IMPACTS AND ASSOCIATED PERFORMANCE MEASURES

Constrained MFRS Expansion Option
Conduct All Necessary Research and Collect Limited New Data

Impacts	Performance Measures
System Condition	Miles by Pavement Type and Condition Lane-Miles by Pavement Type and Condition VMT/Lane-Mile by Pavement Type and Condition Number of Deficient Bridges (Federal-aid systems only) Various Physical Condition Deficiency Indexes
System Usage	VMT/Capacity-Mile (Peak and off-peak) PMT/Lane-Mile (Auto, bus, truck, and motorcycle) Auto Occupancy (Peak and off-peak) Ton-Miles of Freight/Mile Tons/Truck
Safety	Fatalities/10^8 VMT Injuries/10^8 VMT (Includes fatalities) Nonfatal Injuries/10^8 VMT Fatal Accidents (Number and cost)/10^8 VMT Nonfatal Injury Accidents (Number and cost)/10^8 VMT Property-Damage-Only Accidents (Number and cost)/10^8 VMT Percent VMT on Roads with Insufficient Skid Resistance
Comfort and Convenience	Percent VMT versus V/C (Overall travel speed in urban areas) Percent VMT on Deficient Highways by Pavement Type Percent Trucks and Buses Percent VMT on Inadequate Horizontal and Vertical Curvature Percent VMT on Narrow Lane Roads Percent VMT with Full, Partial, or No Access Control Percent VMT on Divided and Undivided Highways
Vehicle Operating Costs (VOC)	VOC ($)/1,000 VMT (Overall, peak, and off-peak) VOC ($)/1,000 VMT by Vehicle Type VOC ($)/1,000 VMT by Design Type and Pavement Type and Condition Gallons/1,000 VMT by Fuel Type (Overall, peak, and off-peak) Gallons/1,000 VMT by Vehicle Type Gallons Consumed by Autos/1,000 PMT (Peak and off-peak)
Accessibility	Accessibility = Subjective Function of Changes in Traveltime and Vehicle Operating Cost Impacts Accessibility Index = f (Changes in traveltime and vehicle operating cost impacts) (Hours or $)/1,000 VMT (Overall, peak, and off-peak) Person-Hours/1,000 VMT (Peak and off-peak) (Hours or $)/1,000 VMT by Vehicle Type (Hours or $)/1,000 VMT by Design Type & Pavement Type & Condition (Hours or $)/1,000 PMT (Overall, peak, and off-peak) Congestion Index = Peak (Hours/VMT) ÷ Off-Peak (Hours/VMT) Delay Index = Percent Traveltime in Delay Mode (Peak and off-peak)
Air Pollution	CO, HC, and NO_x Tons/10^6 VMT (Overall, peak, and off-peak) CO, HC, and NO_x Tons/10^6 VMT by Vehicle Type CO, HC, and NO_x Tons/10^6 VMT by Land Use

Additional Performance Measures

Based on the preceding options, the system condition, safety, comfort and convenience, and vehicle operating cost performance measures are fairly comprehensive and no additional performance measures are needed in these areas.

In the area of system usage, several performance measures need to be added that address freight movement. The first is ton-miles of freight moved by commodity type. This requires that data on commodity type be collected when trucks are weighed. Likewise, truckload factors would need to be obtained that reflect the portion of total capacity being used, taking both weight and volume into consideration. In addition, ton-miles of different commodities moved by intercity bus would be obtained through a survey of cargo type and weight.

In the accessibility area, traveltime contours need to be developed for each urbanized area or representative urbanized areas for each State. This information, along with the percent of total population within each contour, will enable one to measure the percent of population within "x" minutes of the city center, etc. For rural areas, typical point-to-point traveltimes will be required for selected rural trips, including city-to-city trips, requiring the actual measurement of traveltime between the points. In the air pollution area, a number of urbanized area air quality measurements must be taken in order to establish air quality indexes for each urbanized area.

Possible Performance Measures

Table 6 contains a list of possible performance measures that can be developed under this option.

TABLE 6
IMPACTS AND ASSOCIATED PERFORMANCE MEASURES
Comprehensive MFRS Expansion Option
Extensive Data Collection Effort

Impacts	Performance Measures
System Condition	Miles by Pavement Type and Condition Lane-Miles by Pavement Type and Condition VMT/Lane-Mile by Pavement Type and Condition Number of Deficient Bridges (Federal-aid systems only) Various Physical Condition Deficiency Indexes
System Usage	VMT/Capacity-Mile (Peak and off-peak) PMT/Lane-Mile (Auto, bus, truck, and motorcycle) Auto Occupancy (Peak and off-peak) Ton-Miles of Freight/Mile Tons/Truck Ton-Miles of Freight/Mile by Commodity Type Percent of Total Truck Capacity Utilized/Mile Bus Ton-Miles of Freight/Mile by Commodity Type
Safety	Fatalities/10^8 VMT Injuries/10^8 VMT (Includes fatalities) Nonfatal Injuries/10^8 VMT Fatal Accidents (Number and cost)/10^8 VMT Nonfatal Injury Accidents (Number and cost)/10^8 VMT Property-Damage-Only Accidents (Number and cost)/10^8 VMT Percent VMT on Roads with Insufficient Skid Resistance
Comfort and Convenience	Percent VMT versus V/C (Overall travel speed in urban areas) Percent VMT on Deficient Highways by Pavement Type Percent Trucks and Buses Percent VMT on Inadequate Horizontal and Vertical Curvature Percent VMT on Narrow Lane Roads Percent VMT with Full, Partial, or No Access Control Percent VMT on Divided and Undivided Highways
Vehicle Operating Costs (VOC)	VOC ($)/1,000 VMT (Overall, peak, and off-peak) VOC ($)/1,000 VMT by Vehicle Type VOC ($)/1,000 VMT by Design Type & Pavement Type & Condition Gallons/1,000 VMT by Fuel Type (Overall, peak, and off-peak) Gallons/1,000 VMT by Vehicle Type Gallons Consumed by Autos/1,000 PMT (Peak and off-peak)
Accessibility	Accessibility = Subjective Function of Changes in Traveltime and Vehicle Operating Costs Impacts Accessibility Index = f (Changes in traveltime and vehicle operating costs impacts) (Hours or $)/1,000 VMT (Overall, peak, and off-peak) Person-Hours/1,000 VMT (Peak and off-peak) (Hours or $)/1,000 VMT by Vehicle Type (Hours or $)/1,000 VMT by Design Type & Pavement Type & Condition (Hours or $)/1,000 PMT (Overall, peak, and off-peak) Congestion Index = Peak (Hours/VMT) ÷ Off-Peak (Hours/VMT) Delay Index = Percent Traveltime in Delay Mode (Peak and off-peak) Percent Population Within "x" Minutes of City Center (Urbanized only) Point-to-Point Traveltimes for Typical Rural Trips Including City-to-City Trips
Air Pollution	CO, HC, and NO_x Tons/10^6 VMT (Overall, peak, and off-peak) CO, HC, and NO_x Tons/10^6 VMT by Vehicle Type CO, HC, and NO_x Tons/10^6 VMT by Land Use Air Quality Index by Urbanized Area

Summary and Conclusion

Table 7 summarizes the possible performance measures under each of the five options. The Available Data and the Implemented MFRS Options are too limited to be of much value and the year-to-year comparability of resultant performance measures is questionable. These options do not provide the necessary system management tools and, therefore, have been rejected. The Augmented MFRS Option, the first option built around a "fixed panel" of sections, increases the number of performance measures and their reliability but limits the scope of the system usage area and accuracy of the performance measures in the vehicle operating cost and accessibility areas. The Constrained MFRS Expansion Option incorporates a limited amount of additional information which improves the overall accuracy and sensitivity of many of the performance measures and adds new dimensions in system usage in terms of people and freight movement. The Comprehensive MFRS Expansion Option, while adding several additional performance measures and improving the overall accuracy of the measures, is the most expensive and demanding of the States to the point of being unreasonable.

Many other options could have been developed, but those presented adequately cover the practical limits of the scope of performance monitoring. With the above thoughts in mind, the Constrained MFRS Expansion Option is concluded to be the most practical and prudent option, and this will be the basis for continued efforts at establishing a highway performance monitoring system.

IV. THE SELECTED HPMS APPROACH - CONSTRAINED MFRS EXPANSION OPTION

Data Assembly and Collection Concepts

Monitoring highway performance will require periodic "measurements," on a sample basis, of the condition and the physical, operational, and usage characteristics of the highways. The question of how these data will be obtained is paramount to the implementability of the overall plan. While it is assumed there is a "technically best" way to collect each data element, manpower requirements and cost considerations are necessary in order to arrive at the most practical sampling plan.

The HPMS data collection requirements have been grouped into four categories: primary sample--section specific data necessary for the continuing base sample of sections; subsample--section specific data that either are not required for or cannot be reasonably obtained for the continuing base sample; case study--limited to typical data that reasonably cannot be obtained for a sample or subsample of sections; and areawide data--nonsection specific data.

TABLE 7

SUMMARY OF IMPACTS AND ASSOCIATED PERFORMANCE MEASURES — ALL OPTIONS

Impacts	Performance Measures				
	Available Data Option	Implemented MFRS Option	Augmented MFRS Option	Constrained MFRS Expansion Option	Comprehensive MFRS Expansion Option
System Condition	Miles by Pavement Type (1. National by Federal-aid, State, and Local; 2. By State; 3. By State - Surfaced FAP Mileage by Surfaced Type and Width) → Superseded				
		Miles by Pavement Type → Superseded Lane-Miles by Pavement Type → Superseded VMT/Lane-Mile by Pavement Type → Superseded			
			Miles by Pavement Type and Condition →	→	→
			Lane-Miles by Pavement Type and Condition →	→	→
			VMT/Lane-Mile by Pavement Type and Condition →	→	→
	Number of Deficient Bridges (FA Systems only) →	→	→	→	→
			Various Physical Condition Deficiency Indexes →	→	→
System Usage	VMT/Lane-Mile (FAP and FAU Only) → Superseded				
	Auto Occupancy (National) →	→	→	→ Superseded	→
	Truck Ton-Miles (National) →	→	→	→ Superseded	→
		VMT/Capacity-Mile (Peak and Off-Peak) →	→	→	→
				PMT/Lane-Mile (Auto, Bus, Truck, and Motorcycle) →	→
				Auto Occupancy (Peak and Off-Peak) →	→
				Ton-Miles of Freight/Mile Tons/Truck →	→
					Ton-Miles of Freight/Mile by Commodity Type Percent of Total Truck Capacity Utilized/Mile Bus Ton-Miles of Freight/Mile by Commodity Type
Safety	Fatalities/10^8 VMT →	→	→	→	→
	Injuries (All Nonfatal)/10^8 VMT →	→	→	→	→
	Fatal Accidents/10^8 VMT →	→	→	→	→
	Nonfatal Injury Accidents/10^8 VMT → (By TA-1 Table Breakdowns - Federal-Aid System and Other)	→	→	→	→
			Injuries/10^8 VMT (Includes Fatalities) →	→	→
			Property-Damage-Only Accidents (Number and Cost)/10^8 VMT →	→	→
				Percent VMT on Roads with Insufficient Skid Resistance →	→
Comfort and Convenience	Little or Nothing Possible	Percent VMT Vs. V/C (Overall Travel Speed in Urban Areas) →	→	→	→
		Percent VMT with Full, Partial or No Access Control →	→	→	→
		Percent VMT on Divided and Undivided Highways →	→	→	→
			Percent VMT on Deficient Highways by Pavement Type →	→	→
			Percent Trucks and Buses →	→	→
			Percent VMT on Inadequate Horizontal and Vertical Curvature →	→	→
			Percent VMT on Narrow Lane Roads →	→	→

TABLE 7 (con.)

SUMMARY OF IMPACTS AND ASSOCIATED PERFORMANCE MEASURES - ALL OPTIONS

Impacts	Performance Measures				
	Available Data Option	Implemented MFRS Option	Augmented MFRS Option	Constrained MFRS Expansion Option	Comprehensive MFRS Expansion Option
Vehicle Operating Costs (VOC)			VOC ($)/1000 VMT (Overall, Peak, and Off-Peak)	→	→
			VOC ($)/1000 VMT by Vehicle Type	→	→
			VOC ($)/1000 VMT by Design Type and Pavement Type and Condition	→	→
	Miles/Gallon by Vehicle Type (National) →	→	Superseded		
	Gallons/1000 VMT by State (Highway Statistics) →	→	Superseded		
	Miles/Gallon by State (Highway Statistics) →	→	Superseded		
			Gallons/1000 VMT by Fuel Type (Overall, Peak, and Off-Peak)	→	→
			Gallons/1000 VMT by Vehicle Type	→	→
				Gallons Consumed by Autos/1000 PMT (Peak and Off-Peak) →	→
Accessibility	Miles/Square Mile by State →	→	Superseded		
			Accessibility = Subjective Function of Changes in Traveltime and Vehicle Operating Cost Impacts	→	→
			Accessibility Index = f (Changes in Traveltime and Vehicle Operating Cost Impacts)	→	→
					Percent Population Within "x" Minutes of City Center (Urbanized Only)
					Point to Point Traveltimes for Typical Rural Trips Including City to City Trips
			(Hours or $)/1000 VMT (Overall, Peak, and Off-Peak)	→	→
			(Hours or $)/1000 VMT by Vehicle Type	→	→
			(Hours or $)/1000 VMT by Design Type and Pavement Type and Condition	→	→
			Congestion Index = Peak (Hours/VMT) ÷ Off-Peak (Hours/VMT)	→	→
			Delay Index = Percent Traveltime in Delay Mode (Peak and Off-Peak)	→	→
				Person-Hours/1000 VMT (Peak and Off-Peak) →	→
				(Hours or $)/1000 PMT (Overall, Peak, and Off-Peak) →	→
Air Pollution	Little or Nothing Possible	Little or Nothing Possible			
			CO, HC, and NO_x Tons/10^6 VMT (Overall, Peak, and Off-Peak)	→	→
			CO, HC, and NO_x Tons/10^6 VMT by Vehicle Type	→	→
				CO, HC, and NO_x Tons/10^6 VMT by land use →	→
					Air Quality Index by Urbanized Area

Primary sample data will serve as the base for system condition, system usage, and operational characteristics; the continuing reference base for deriving performance measures and resultant impacts; and the major data base for various analytical models. The primary sample will be monitored continually, with individual section specific elements measured and updated on a cyclical basis.

The chosen method of sampling section specific information consists of randomly selected sections, or "panel," which would remain "fixed" after the initial sampling, and from this panel, data will be inventoried on a cyclical basis. This means of obtaining data is more efficient because: (a) the need for the periodic drawing of an entirely new sample is eliminated; (b) the need to sample many of the data elements every cycle is eliminated; and (c) data elements that change over time can be updated on a cyclical basis, the length of the cycle being dictated by the known statistical characteristics of individual elements, intended use and accuracy needed, and the time/cost required to collect and report such data.

The subsample, a portion of the primary sample, will serve specific data requirements that can be met practically at a significantly lower sampling rate than the primary sample rate. The lower sampling rate is feasible because of the limited variability of the data itself, the high cost and/or manpower necessary to collect and report the data, or the precision needed.

Certain key elements required by the HPMS (e.g., vehicle type distribution) are very difficult to obtain because they are cost/personnel intensive. These data, however, represent critical elements in the highway transportation planning process and are imperative to the adequate assessment of many of the policy and program alternatives that have been emerging and are anticipated in the future.

Data such as vehicle type distribution, vehicle occupancy, and truck weights will be obtained either on a subsample basis or through case studies. The specific means for obtaining this information will be determined through feasibility analyses.

Areawide data will consist of statewide and/or sub-State control summaries, and will include such items as: land area, population, and PMT served by transit.

Technical Approach to Determine Performance Measures

As a part of the impact selection process, a study was made of each potential impact. In addition to documenting the need for the impact, the studies specified: potential performance measures for estimating the impacts; the methodology for estimating the performance measures; and the overall data needs, whether or not the data were available. Certain technical approaches were identified to obtain the performance measures.

Technical approaches for obtaining the performance measures shown in Table 7 for each impact were identified. For example, it was determined that the system condition performance measures would be obtained for each primary sample section as a function of such factors as pavement condition and number of lanes. Specific performance measures, e.g., VMT per lane-mile by pavement type and condition, would also be obtained. Since it is also known that the system condition impact has an effect to some degree on all other impacts, these influences will be explored and various physical condition deficiency indexes will be developed.

Similar approaches were developed for each of the performance measures for each of the impact areas.

Data Requirements

At first glance, the data requirements for the HPMS appear to be rather large and appear to require continuously high levels of effort to be met. Significant reductions in this ominous appearance can be made by noting that very few of the data elements will change over time unless a capital improvement is made. Only ADT, future ADT, "K" factor, percent trucks, pavement condition, skid resistance, and drainage adequacy will change over time and will need to be updated on a cyclical basis. All other data elements will be updated only when improvements are made. All data elements are required for the derivation of the vehicle operating cost performance measures with the exception of four data elements--number of bridges, prevailing type of development, skid resistance, and drainage condition. All remaining measures can be calculated by adding just these four data elements to the collection effort.

The overall data collection effort for the individual HPMS data elements involves the application of one of six methods:

1. Primary sample of sections - "fixed panel"
2. Subsample of sections - a subset of the "fixed panel"
3. Case studies
4. Existing sources within FHWA/DOT
5. Secondary sources
6. FHWA research (contract and in-house)

Of these six methods, it should be noted that only the first three would require field data collection efforts.

Primary Sample of Sections Data Elements

Data elements presently contemplated for the primary sample of sections and their intended use are listed in Table 8. A question mark in the table indicates that further work will be necessary in Phase II to determine whether the data element will be needed for the indicated impact. The first several columns of this table indicate the impact area for which the various data elements will be used.

The only additional data included in the "General Data" category that are not needed for individual impact assessments are the connecting link code, jurisdiction, right-of-way width, type of improvement, and capital cost of improvement. The type of improvement data item is necessary to indicate that change has taken place and the generalized nature of the change. It is intended that an improvement will trigger an update of all primary sample data elements for affected sections. Capital improvement cost data associated with various improvement types will be correlated with section specific information to provide input to cost-benefit and cost-effectiveness analyses, the so-called "bang for the buck" evaluations.

Analysis of future policy and program alternatives will require only one additional data element--future ADT. This data element, along with the data elements needed to measure current performance, will serve as input to the various analysis models.

Other Sources of Data Elements

The remainder of the HPMS data requirements are to be filled from sources other than the primary sample. Table 9 indicates how each remaining data element will be obtained (source) and the categories in which it will be used. The decision whether data will be obtained from a subsample of primary sample sections or through a case study will be based on analyses of the statistical properties of individual data elements, the cost and manpower needed to collect the data, and the intended use of the data.

Areawide data elements will be assembled and reported as geographic area summaries. These data will provide HPMS with general information and/or areawide totals not available elsewhere.

It eventually will be feasible to assemble some of the previously discussed areawide data from existing reporting sources. Capital investment costs, other financial data, mileage, and travel summaries

TABLE 8
FIELD DATA TO BE OBTAINED FOR PRIMARY SAMPLE OF SECTIONS
AND CATEGORIES IN WHICH DATA WILL BE USED*

Data Elements	Data Required to Address Impact Areas							General Data	Data for Future Program Analyses
	System Condition	System Usage	Safety	Comfort & Convenience	Vehicle Operating Costs	Accessibility	Air Pollution		
Federal-Aid System	X	X	X	X	X	X	X	X	X
Functional Classification	X	X	X	X	X	X	X	X	X
Connecting Link Code								X	X
Jurisdiction								X	X
No. of Lanes	X	X	X	X	X	X	X	X	X
Degree of Access Control		X	X	X	X	X	X	X	X
Median Type		X	X	X	X	X	X	X	X
Median Width		X	X	X	X	X	X	X	X
Section Length	X	X	X	X	X	X	X	X	X
Grades			?	X	X	X	X	X	X
Horizontal Curves			?	X	X	X	X	X	X
Pavement Types	X		?	X	X	?		X	X
Pavement Condition	X		?	X	X	?		X	X
No. of Intersections			?	X	X	X	X	?	X
No. of Bridges	X		?	?				X	X
No. of At-Grade RR X'ings	X		X	X	X	X		X	X
Type of Development			?	X			?	X	X
Right-of-Way Width								X	X
ADT by Time of Day	X	X	X	X	X	X	X	X	X
Future ADT									X
% Trucks	?	X	?	X	X	X	X	X	X
Parking		X	?	X	X	X	X	X	X
Type of Operation		X	?	X	X	X	X	X	X
Speed Limit			?		X	X	X	X	X
Shoulder Type	?	X	?	X	X	X	X	X	X
% Passing Sight Distance	?		?		X	X	X	X	X
Terrain	?	X	?	X	X	X	X	X	X
Lane Width	?	X	?	X	X	X	X	X	X
Shoulder Width	?	X	?	X	X	X	X	X	X
Approach Width		X	?	X	X	X	X	X	X
% Green Time		X		X	X	X	X	X	X
Population Size Code		X		X	X	X	X	X	X
Urban Location		X		X	X	X	X	X	X
"K" Factor		X		X	X	X	X	X	X
"D" Factor		X		X	X	X	X	X	X
Skid Resistance	X		X					X	X
Drainage Condition	X							X	X
Improvement Type								X	X
Cap. Cost of Improvement								X	X

NOTE: X = Used; ? = May be Used--to be Determined in Phase II.

* If a data item is used to calculate speed and speed is used in a given area, then the data item is considered to be used in area.

TABLE 9

INFORMATION TO BE OBTAINED FROM OTHER THAN PRIMARY SAMPLE

Type of Information (By Source Category)	Data Required to Address Impact Areas							General Data	Data for Future Program Analyses	Remarks
	System Condition	System Usage	Safety	Comfort & Convenience	Vehicle Operating Costs	Accessibility	Air Pollution			
(Field Subsample/Case Study)										
Speeds			?		X	X	X			Controls for Prediction Relationships
Traveltime			?		X	X	X			Controls for Prediction Relationships
Vehicle Occupancy		X				X		X	X	Autos, Trucks, Buses, and Motorcycles
Average Carried Load		X							X	By Truck Type
Vehicle Type Distribution		X	?	?	X	X	X	X	X	By Time of Day
(Areawide Data)										
Bus PMT		X				X		X	X	Intercity, School & Transit Service Only
Capital Investment Cost								X		By FA Project (Including Non-FA); Functional Sys., Imprvmt. Type for Rural, S. Urban, & Individual Urbanized Areas
Miles								X		Imprvmt. Type for Rural, S. Urban, and Individual Urbanized Areas
DVMT								X		See Miles
Maintenance Costs								X		Estimated
Future Mileage									X	See Miles
Future VMT									X	See Miles
Land Area								X		See Population
Population								X		Rural, Small Urban, and Individual Urbanized Areas
(Existing Reporting Sources)										
ADT Distributions		X	X	X	X	X	X	X		By Highway Design Type from ATR's
Fat., Inj., & Accident Data			X							TA-1 Table, NHTSA-FARS and NASS
Bus Trips and PMT		X						X		FARE System (UMTA)
Bridge Data	X		?		?	?		X		National Bridge Inventory Data
At-Grade RR Crossing Data	X		X		X	X		X		National Highway-RR Crossing Inventory
Licensed Drivers								X		Highway Statistics
Registered Vehicles								X		Highway Statistics
Total Revenues								X		Highway Statistics
Total Miles								X		Highway Statistics
Expenditures								X		Highway Statistics
(Other Sources)										
ADT Distributions		X	X	X	X	X	X	X		By Time of Day, ADT Group, Design Type
Unit Vehicle Operating Costs					X					For Curves, Grades, Idling, Speed Change Cycles by Vehicle Type
Values of Time						X				By Vehicle Type
Speed Change				?	X	X				
Accident Costs			X							For Fatalities, Injuries, and all Accidents by Vehicle Type & Location
Vehicle Age Distribution		X	?		X		X	X		VMT Driven by Autos of Various Ages
Fuel Consumption Rate Tables					X					See Unit Vehicle Operating Costs
Emission Rate Tables							X			By Vehicle Type
Fat., Inj., & Accident Rates			X							

NOTE: X = Used; ? = May be Used--To be Determined in Phase II.

will be available from the FHWA Highway Statistics Division and the UMTA FARE system is expected to serve as a source of transit data. Table 9 also indicates other data that will be obtainable from existing sources.

All of the data to be obtained from secondary sources will serve as input to the analytical procedures that will be developed to analyze performance data. This type of data for the most part is already available from previous studies and activities by other private and Federal Government agencies. Unit vehicle operating cost tables, time values, excess times for speed change cycles, accident costs, and fuel consumption rate tables will necessarily be developed through research efforts. Research efforts will be limited to in-house FHWA-conducted efforts and to some contract research when necessary.

Future Data Considerations

In addition to the many technical and coordination problems that lie ahead, there also are several institutional problems that will have a direct impact on the HPMS and will have to be considered in its development. These additional problems include:

- The 1980 Census and subsequent censuses will result in the designation of new urbanized areas and urban places.
- The functional systems (required by Title 23 as a basis for Federal-aid systems) will require periodic updating.
- A mechanism for developing consistent travel forecasts nationwide will have to be established.

The 1980 Census and subsequent censuses will have direct implications with regard to the continuing evaluation of highway systems performance. The designation of new urbanized and Federal-aid urban areas and the absorption of existing urban places by urbanized areas all have a direct effect on the urban/urbanized/rural mileage and functional systems designations. The net effect of such occurrences is that all mileage contained within the boundaries that change from rural to urban, etc., will also undergo change in functional systems assignments. The HPMS consequences of changes of this nature are:

- Some highway sections initially monitored as rural will become urban.
- Functional reclassification of mileage will occur.
- The data base and analytical tools, including models, will differ for rural and urban facilities.

Functional classification is presently required by Title 23. Should future changes in Federal-aid highway legislation modify or eliminate the requirement for Federal-aid systems and, therefore, the requirement for functional systems, there will still be a great need for functional classification. It should be recognized that periodic updating of the functional systems will be required to account for changed usage patterns, new facilities, and the previously noted changing urban boundaries. It is anticipated that functional classification updates will be necessary on a 5-year cycle.

No formal requirement presently exists for the forecasting of State or national vehicle miles of travel by functional system. The HPMS analytical models and tools that will be developed and applied in subsequent phases of this effort are among a number of activities that are dependent upon the availability of such future travel estimates. As a policy planning mechanism, it is imperative that the analytical procedures developed as part of the overall HPMS be sensitive to travel forecast alternatives. Hence, basic travel forecasts are of paramount importance to the HPMS--the capability to assess any future policy or program alternative will not exist without travel projections.

V. IMPLEMENTATION OBJECTIVES

The basic implementation of HPMS is envisioned to be a four-phase undertaking resulting in a time-phased implementation procedure. The four phases are:

Phase I - Concept Development.--Phase I focused on the initial development of the overall monitoring system concepts. The primary product of this phase is the documented project framework on which subsequent phases can be based.

Phase II - Development of Technical Procedures.--Phase II will focus on the final identification of performance measures and impacts and the preliminary design of: (1) technical procedures for deriving performance measures and impacts, including the preparation and letting of contracts to conduct necessary research; (2) a data collection plan and expanded reporting requirements for the MFRS; and (3) an implementation plan and procedures.

Phase III - Final Design of Field Implementation Procedures.--Phase III will finalize implementation instructions and will develop the expanded MFRS guidelines, formats, and instructions, including the development of software to aid in the processing and editing of the data. A major focus of this phase will be the formalized review and approval process associated with the directives system and national data collection activities.

Phase IV - Development of Centralized Analytical Procedures.--Phase IV will formalize all concepts and procedures developed in the first three phases. Analytical procedures, computerized where practical and necessary, will be developed to derive and analyze performance measures and impacts and to test the consequences of alternative policies, programs, investment strategies, etc. In addition, software will be designed and developed that will establish and maintain the data in the form of a continuing historical record. This record will be developed so as to accommodate initial base year data and updates for future years to facilitate comparative analyses and trends of these data.

Time-phase implementation of the HPMS could take a number of forms--it is premature at this time to develop "specifics" regarding time-phasing; however, the following example illustrates the basic concept:

Cycle 1

- First Year (first cycle only) - Primary sample data.
- Second Year - Case study and/or subsample data plus capital improvement updates to primary sample.
- Third Year - Condition reappraisal on primary sample plus capital improvement updates.
- Fourth Year - Similar to second year.

Cycle 2

- Fifth Year - Major update to primary sample including modification as necessary to functional system, samples, and new traffic data.
- Sixth Year - Similar to second year.

This cyclical process will result in a smoothing of the peaking tendencies of data collection efforts, which will equalize personnel requirements over time and lead to a more efficient data gathering process.